

Physical Sub-channel-Based Datacasting Scheme Over DTMB Systems

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Abstract—The China-based digital television terrestrial multimedia broadcasting (DTMB) has been recently announced as the fourth international digital television terrestrial broadcasting (DTTB) standard for its outstanding reception performance. Since traditional DTMB systems could only support TV programs with the same interleaving, constellation mapping, channel coding and thus the same quality of service (QoS), an enhanced DTMB multiservice system was further studied. However, due to the conventional long-time interleaving, the flexibility and the power saving capability for the new-service receivers could not be materialized. To solve this problem, the concept of time-frequency domain physical sub-channel (PSC) is studied for the DTMB, based on which a novel datacasting scheme over DTMB systems in a backward compatible manner is proposed in this paper. The proposed system has been simulated and tested in the lab, and the testing results are shown in this paper¹.

keywords—Digital Television Terrestrial Multimedia Broadcasting (DTMB); Physical Sub-channel (PSC); Datacasting; Convolutional Interleaving; Backward Compatibility

I. INTRODUCTION

As it is known to all, digital TV (DTV) services are usually broadcasted by means of terrestrial, satellite and cable networks, among which the digital television terrestrial broadcasting (DTTB) is the most important. Up till now, four international DTTB standards have been announced and implemented all over the world, that is, the USA-based ATSC (Advanced Television System Committee) standard, the Europe-based DVB-T (Digital Video Broadcasting-Terrestrial) standard, the Japan-based ISDB-T (Integrated Services Digital Broadcasting- Terrestrial)[1] standard and the China-based DTMB (Digital Television

Terrestrial Multimedia Broadcasting) standard [2][3]. Recently, with massive development of mobile devices, such as smart phones and PDAs (personal digital assistants), and increasing demand to revive the lack of the spectrum while providing multiple services, there is a wide interest in extending the original digital television terrestrial broadcasting (DTTB) systems to include additional multimedia services other than terrestrial TV programs, especially mobile TV services, namely datacasting. For example, the DVB-H (DVB-Handheld) [4] and the ATSC-MH (ATSC Mobile/ Handheld) [5] standards have been investigated to include mobile TV

services to improve the DVB and the ATSC systems, respectively. Meanwhile, with the concept of the physical layer pipes (PLPs), the second generation digital video broadcasting terrestrial (DVB-T2) standard is also proposed to support the simultaneous transmissions of both the terrestrial and mobile TV services [6].

Different from other DTTB systems, the DTMB uses time domain synchronous-orthogonal frequency division multiplexing (TDS-OFDM) instead of cyclic prefix-OFDM (CP-OFDM) as its key technology, which results in higher spectral efficiency and faster synchronization. It has been widely proven to be able to accommodate both high definition and standard definition TV programs under either fixed or mobile environment[2][3]. However, when considering the datacasting scenario in the DTMB, the same channel coding, constellation mapping and interleaving mode within a single radio frequency channel make different quality of service (QoS) requirements of different services almost impossible, such as the data throughput and the receiver sensitivity. Besides that, since the conventional DTMB receivers have been widely used, it is highly desirable to only modify the DTMB transmitter to support various services yet without any modification on the existing receivers. As a result, an enhanced DTMB multiservice system was studied for the embedded transmission of multiple services in DTMB systems [7].

However, due to the long-time conventional interleaver with the interleaving/de-interleaving delay of 100/300 ms in

DTMB, which helps DTMB systems provide a better immunization capability and diversity capability, there is large external memory storage and long-time delay at the DTMB receiver side. In addition, the channel decoding process requires much external memory storage as well. As a result, as discussed in [7], on one hand, the new-service receivers need to be turned on all the time and can only obtain the designated data after continuously performing the de-interleaving on the whole received signals, which consumes much more power. On the other hand, since the mobile/handheld receivers with limited sizes favor lower power consumption, the long-time interleaving module, which needs large external memory storage and is difficult to be integrated, should be avoided.

Aiming at the problem mentioned above, by analyzing the data multiplexing pattern before and after the convolutional interleaving in DTMB, the concept of the physical sub-channel (PSC) has been established in our previous work in [8], where one or several PSCs of the whole transmission resource are used for the independent transmission of multiple services. Based on the PSC, a novel approach to handle datacasting for DTMB systems in a stringent backward compatible manner is proposed. In this scheme, the new-service receivers can easily determine which portion of the received signals actually has to

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be received and further processed while ignoring the rest, whereas the conventional DTMB receivers still work well without any change. Moreover, the additional channel coding, constellation mapping and time interleaving of new services could vary from service to service. Both simulation and testing in lab indicate that this scheme facilitates the mobile/handheld receivers as the overall power consumption is much lower and the receiver complexity is greatly reduced.

The remaining paper is organized as follows. In Section II, the DTMB system model together with the structure of the convolutional interleaver and de-interleaver and the time-frequency domain PSC for DTMB systems are reviewed in turn. The transmitter model of the enhanced DTMB datacasting system is proposed in Section III. Section IV describes the reception performance of the proposed system with both computer simulation and laboratory testing. Finally, the conclusions are drawn in Section V.

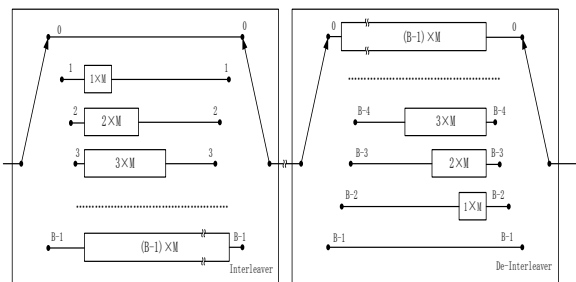


Fig. 1 The structure of convolutional interleaver/de-interleaver

II. ANALYSIS ON PSC IN DTMB

A. Review of DTMB Model

In DTMB [2], at first, all the data from TV programs are first packed into 188-byte TS packets. According to [9], in DTMB, every 188-byte TS packets has the packet header (PH) of 4 bytes, 13 bits of which are adopted as the program identification (PID) to identify the specific programs in the existing DTMB receivers. And then, the TS packets from different services are multiplexed into a single TS stream at the transmitter side. After that, to overcome the impairment of the noise and fading caused by wireless channels, the scrambling, the channel coding, the constellation mapping, the convolutional interleaving, and the frame assembling are further applied to this single TS stream in turn. And thereinto, the forward error correction (FEC) code is used as the channel coding, which is the concatenation of outer BCH (762, 752) and inner low density parity check (LDPC) codes with three different code rates of 0.4(7488, 3048), 0.6(7488, 4572), and 0.8(7488, 6096). After that, the output binary sequence of the FEC coding is modulated to the M-ary quadrature amplitude modulation (M-QAM) symbols to form the 3744-symbol long basic data block (BDB). In DTMB systems, the typical constellation mapping modes of 4-QAM, 16-QAM, 32-QAM, and 64-QAM are supported. As shown in Fig. 1, after the constellation mapping, the convolutional interleaver is used across many BDBs, with B and M as the number of the interleaving branches and the interleaving depth, respectively. In DTMB, B is set to 52, while there are two options for M , i.e., 240 and 720 respectively, and the corresponding interleaving/de-interleaving delays are 170 and 510 BDBs, respectively. Then, the frame body (FB) is formed by adding 36-symbol transmission parameters signaling (TPS) before the

convolutional data block (CDB) after the interleaving. For multicarrier mode, the data symbols are further modulated by the inverse fast Fourier transform (IFFT) operation to form the FB. After that, the pseudo random noise (PN) sequence is padded as the frame header (FH) between two adjacent FBs to form a signal frame. Finally, the baseband processing and up-converting operations are applied.

At the receiver's side, after the synchronization process, the channel state information is obtained via the channel estimation, and the FB is then equalized and processed by the corresponding inverse operations from the transmitter side.

B. Review of Time-Frequency Domain PSC in DTMB

To improve the flexibility and the power saving capability of the DTMB multimedia service systems in [7], a novel PSC approach in time-frequency domain over DTMB systems is proposed in [8], which is based on the detailed analyses on the one-to-one mapping for the locations of the data symbols before and after the convolutional interleaving. Taking the $M=240$ mode for example, the key issues including how to explore the one-to-one mapping mentioned above and how to allocate the overall DTMB system resource to the individual services with different QoS requirements will be paraphrased in the following. The $M=720$ mode is similar to the $M=240$ mode and will not be detailed in this paper. For more information about the PSC, please refer to [8].

In DTMB, the BDB mentioned above is 3744-symbol long, i.e., there are 3744 payload sub-carriers in one frame. When using the convolutional interleaving mode of $M=240$, one BDB can be divided into 3 so-called basic sub-data blocks (BSDBs), each of which includes $3744/3=1248$ payload sub-carriers. Similarly, after the time interleaving, the $(52p+q)$ -th ($0 \leq p < 24$, $0 \leq q < 52$) symbol in the n' -th basic BSDB is at the same position as well, i.e., $(52p+q)$ in the $(n'+10q)$ -th convolutional sub-data block (CSDB) and vice versa.

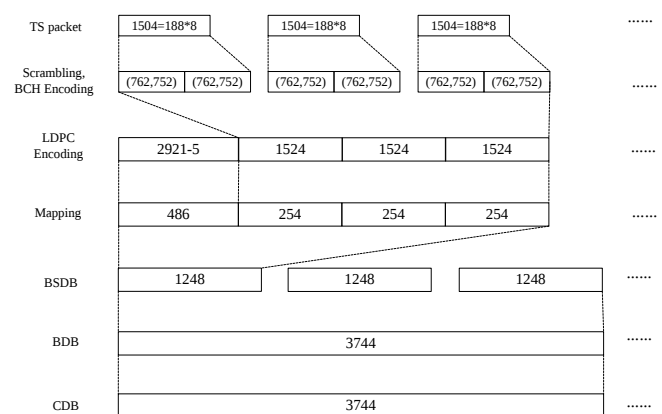


Fig. 2 The one-to-one mapping diagram for 64-QAM/LDPC 0.6

TABLE I
THE NO. OF THE PSC FOR BOTH MODES

MODULATION MODE	LDPC Rate	TS Packet No. K per BDB	PSC No. FOR M=720	PSC No. FOR M=240
16-QAM	0.4	4	40	N/A
	0.6	6	60	20
	0.8	8	80	N/A
64-QAM	0.4	6	60	20
	0.6	9	90	30
	0.8	12	120	40

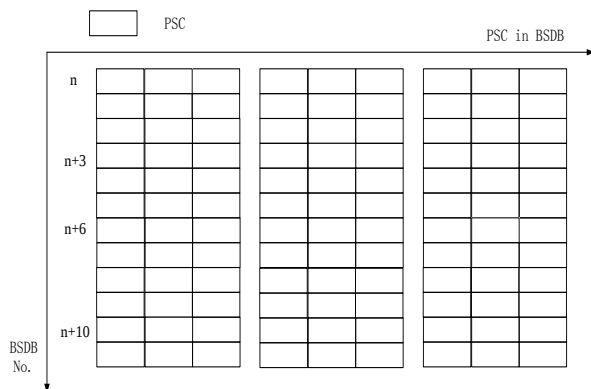


Fig. 3 The allocated resource of one PSC for M=240 mode.

As shown in Fig. 2, take the working mode of 64-QAM/BCH& LDPC 0.6(7488, 4572) in the DTMB system as an example. Similarly, with the definitions of T_n and K for one PSC element, the PSC I_n ($0 \leq n < 10K/3$) of the $M=240$ mode is expressed as

$$I_n = \{T_n \mid n \square i \bmod(10K/3)\}. \quad (1)$$

Moreover, Fig. 3 also shows a PSC example in shadow for the $M=240$ mode.

According to the analysis above, the whole physical channel of DTMB systems could be thus divided into many PSCs. Table I summarizes the PSC numbers for both modes of $M=240$ and $M=720$. Especially, for the $M=240$ mode, since $10K/3$ should be an integer, as shown in Table I, we can see that only the 64-QAM modulation mode can be applied together at any LDPC rate, or only the LDPC 0.6 coding mode can be adapted with any modulation mode. It is necessary to point out that with the PLPs [6] the DVB-T2 is a brand new system and different from its predecessor DVB-T, the PSCs in DTMB are restricted by the rules of the long-time convolutional interleaving/deinterleaving so as to keep the thorough backward compatibility with the conventional DTMB receivers.

III. IMPROVED DTMB DATACASTING SYSTEM

When the PSC concept is applied to the DTMB datacasting scenario, different services independently occupy certain PSCs, so that the new-service receivers can easily obtain the designated data from the corresponding PSCs. On one hand, the receivers would only further process the data in their individual PSCs while turning off some modules in other PSCs, such as the de-interleaving and the decoding. In this way, the power consumption of the newly-designed receivers is efficiently reduced. On the other hand, the additional scrambling, the additional outer coding, the private constellation mapping, and the individual interleaving modes are independent from the standard DTV programs and vary from service to service to obtain different QoS such as the time-delay and the coverage region. In this way, the flexibility of new services is guaranteed. Based on this, an improved DTMB datacasting system in the stringent backward compatible manner without any modification in the DTMB standard receivers is further designed. For simplicity, we focus on analyzing the dual-service case, which includes one original terrestrial DTV program and one additional mobile service. The enhanced DTMB transmitter model is shown in Fig. 4.

According to the throughput requirements of the additional services as well as the working mode of the original service, the PSCs of DTMB systems are individually allocated to all the services.

At first, the TS packets of the additional services are pre-randomized by their individual scramblers, and then pre-encoded by their private outer FEC codes. Any kind of powerful error correcting codes, including the code rate, the error correction capability, and the complexity of encoding and decoding, can be selected depending on the QoS requirements. For example, the bit-interleaved coded modulation with the iterative demapping and decoding (BICM-ID), which has outstanding performance approaching Shannon limit [10], can be adopted.

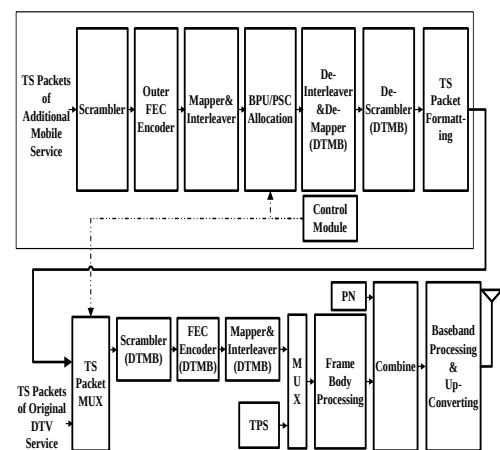


Fig. 4 The typical model of the improved DTMB datacasting transmitter

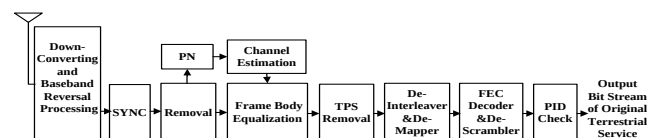


Fig. 5 The typical model of conventional DTMB receivers

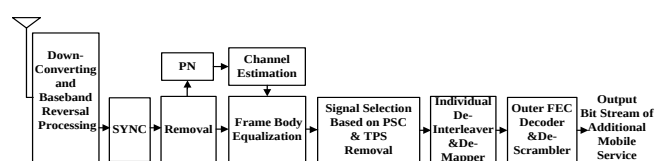


Fig. 6 The typical model of new-service receivers

After that, as demonstrated in [11], the lower-order constellation modulation results in better bit error rate (BER) performance at the same SNR environment, which is more suitable for mobile applications. Therefore, the data stream is modulated by their individual low-order QAM schemes as well as independently interleaved. Without causing any demapping modification to keep the backward compatibility with DTMB standard receivers, signal points after the individual constellation mapping should occupy a subset of the standard higher-order QAM constellations in DTMB systems, and can be any kind of modulation schemes including the enhanced QAM modulation in [7] and the rotated constellation mapping in [12]. Moreover, since the additional mobile service may go through severer multipath fading and faster time varying channels, the mobile/handheld receivers are usually equipped

with limited memory capacity corresponding to the support's shorttime delay. As a result, the interleavers with smaller interleaving depth is highly recommended. Any kind of interleavers, such as the convolutional or block interleavers, could be the candidates.

Next, the symbols after the constellation mapping and interleaving are inserted into their corresponding PSCs by taking advantage of the control module. After that, the operations of standard de-interleaving, demapping and descrambling for the original service are carried out in turn. To be more specific, on one hand, to avoid the conventional long-time interleaving and keep the backward compatibility, the standard de-interleaver is introduced as a counterpart of the exiting DTMB standard interleaver. That is, after the conventional time interleaving in the following, all the additional service would be equivalently interleaved by their private interleavers from the point of the new-service receivers. Similarly, the standard descrambling is carried out. On the other hand, by taking advantage of the lower-order QAM concept mentioned above, the additional service bits are first modulated to lower-order QAM symbols, and then, by introducing the hard-decision demapper in DTMB, the lower-order QAM symbols turn to consecutive bit sequences that are in the form of standard higher-order QAM constellation symbols. As a result, after the exiting of DTMB standard QAM mapping is carried out in the following, all symbols occupy the points within the standard higher-order QAM constellations, which would not cause any demapping difference in conventional DTMB receivers.

And then, the additional service data stream is packed into the form of standard TS packets, where unrelated padding bits including the 4 PH bytes are inserted to help the receiver identify the additional service. After that, all the data streams are multiplexed into a single data stream in the level of standard TS packets.

In order to keep the backward compatibility, the additional services should be decoded properly by the existing DTMB receivers as well. As a result, finally, the traditional standard FEC coding, the mapping, the time interleaving, the FB processing, the baseband processing and up-converting operations are performed on both the original terrestrial broadcasting service and the additional service according to the DTMB standard in turn.

At the receiver side, conventional DTMB receivers still work as usual. As shown in Fig. 5 [2], at first, the existing DTMB receivers receive the multiplexed data. And then, the FB is equalized with the channel information by the synchronization and the channel estimation. After that, the TPS is removed before the existing DTMB receivers de-interleave, demodulate, decode and descramble every data packet. Finally, by identifying the specific PID, the DTMB receivers obtain the desired terrestrial programs while discarding other signals including the additional mobile service.

In contrast, as shown in Fig. 6, all the data blocks are first continuously processed by the same prior operations as in Fig. 5. Then, with the help of the PSCs in time-frequency domain, the new-service receivers can easily select which portion of the received signals belongs to the additional services and would be further processed by using their private deinterleaving,

demapping, decoding and descrambling schemes. As a result, the payload rates of both the original terrestrial and additional services are calculated as

$$R_O = f_s \cdot (1-\eta) \cdot \frac{N_{OFDM}}{N_{Total}} \cdot r_{BCH} \cdot r_{LDPC} \cdot r_M, \quad (2)$$

$$R_A = f_s \cdot \eta \cdot \frac{N_{OFDM}}{N_{Total}} \cdot r_{BCH} \cdot r_{LDPC} \cdot r_{Pad} \cdot r_{InC} \cdot r_{InM}, \quad (3)$$

respectively, where f_s , N_{OFDM} , and N_{Total} are the DTMB standard symbol rate, the payload sub-carrier number, and the total length of one signal frame including the TPS and the PN sequence, respectively, r_{BCH} and r_{LDPC} are the standard rates of BCH code and LDPC code, respectively, r_M denotes the bit number per original constellation symbol, and h , r_{Pad} , r_{InC} and r_{InM} are the PSC occupancy-ratio of the additional service, the ratio of the valid data excluding the padding bits in one new-service TS packet and the outer FEC code as well as the bit number per inner constellation symbol adopted by the additional service, respectively. In this paper, the modulation and channel coding mode for the original DTV service is chosen as 64-QAM/ BCH&LDPC 0.6, which is a most widely used mode for DTMB systems in China. By applying (2) and (3) together with the PSC numbers in Table I, the throughput of a single PSC with its compatible modulation/coding modes showed in Table II.

IV. TYPICAL APPLICATION AND TESTING RESULTS

In this section, the simulation and testing in the lab of this proposed system are presented. The major testing parameters are as follows. The system symbol rate is 7.56 MSPs and the PN mode is 420. In addition, to simplify the implementation of the additional service, for the outer FEC coder, the existing FEC codes in DTMB are adopted as the flexible DTMB multi-rate decoder has been studied in [13] and [14]. For the outer interleaver, the convolutional interleaving method is still adopted with B is 52 and M is 48, so that the corresponding interleaving/de-interleaving delay is only 34 BDBs, much less than the delay of 510 BDBs for the original DTV service in DTMB [2].

Firstly, as mentioned in Section III, when considering the throughput requirements, since the additional service is a mobile TV service with the target bit rate of 384 Kbps per program [15], eight consecutive PSCs in BDBs, i.e., $h=0.1$, should be allocated to support the mobile TV service with the 4-QAM/BCH&LDPC 0.4 mode according to Table II. One possible arrangement of the PSC resource is illustrated in Fig. 7. Meanwhile, the throughput of the terrestrial broadcasting service with the 16-QAM/BCH&LDPC 0.8 mode is 19.5 Mbps to support a high definition TV service, which contains the other 72 PSCs. It is also clear that the receivers of the mobile TV service could be shut down during 9/10 of time slots for the original terrestrial broadcasting service. That is, during 9/10 of time slots, the new-service receivers could turn off the de-interleaver, demodulator, decoder and descrambler, according to its PSC allocation, which can greatly reduce the power consumption in the new-service receivers.

Secondly, when simulated on computers, Table III and

Table IV summarize the system reception performance under AWGN (Additive White Gaussian Noise) channels at the target BER of 1×10^{-6} by using the MATLAB and the fixed point C platforms, respectively. It is noted that the power of constellation points for both services is normalized to avoid the issue of peak to average power ratio (PAPR) increment.

Finally, the laboratory testing of this proposed system on the FPGA testing bed is carried out recently. The testing results under different channel models including the AWGN and multipath channels, namely Brazil X ($X=A, B$) channels, are firstly shown in Table VI. The profiles of the Brazil A and Brazil B are shown in Table V. It can be seen that the laboratory testing results are in great agreement with the computer simulation above. All these indicate that the receiver sensitivity of the new mobile service could be greatly improved while keeping the reception performance of the original terrestrial broadcasting service unchanged.

TABLE II
THE THROUGHPUT OF ONE PSC IN PN420 MODE

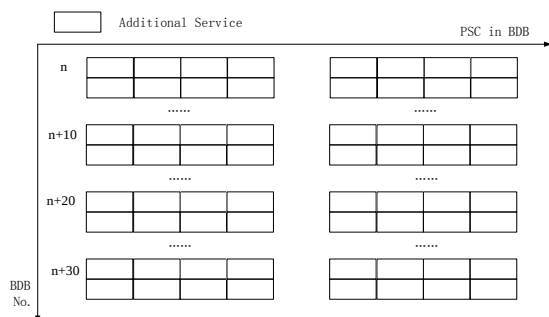
ORIGINAL SERVICE MODE	ADDITIONAL SERVICE MODE	THROUGHPUT OF ONE PSC FOR ADDITIONAL SERVICE	THROUGHPUT OF ONE PSC FOR ORIGINAL SERVICE
64-QAM/0.6	4-QAM/0.4	35.5 Kbps	270.7 Kbps
64-QAM/0.6	4-QAM/0.6	53.2 Kbps	270.7 Kbps
64-QAM/0.6	4-QAM/0.8	71.0 Kbps	270.7 Kbps

TABLE III
THE MATLAB SIMULATION RESULTS BETWEEN MULTIMEDIA SERVICES

ORIGINAL SERVICE		ADDITIONAL SERVICE		
Mode	Threshold	Mode	Threshold	Margin
64-QAM/0.6	13.8 dB	4-QAM/0.4	1.5 dB	12.3 dB
64-QAM/0.6	13.8 dB	4-QAM/0.6	2.9 dB	10.9 dB
64-QAM/0.6	13.8 dB	4-QAM/0.8	5.2 dB	8.6 dB

TABLE IV
THE C SIMULATION RESULTS BETWEEN MULTIMEDIA SERVICES

ORIGINAL SERVICE		ADDITIONAL SERVICE		
Mode	Threshold	Mode	Threshold	Margin
64-QAM/0.6	14.2 dB	4-QAM/0.4	1.6 dB	12.6 dB
64-QAM/0.6	14.2 dB	4-QAM/0.6	3.1 dB	11.1 dB
64-QAM/0.6	14.2 dB	4-QAM/0.8	5.4 dB	8.8 dB



The PSC allocation for the additional service.

TABLE V
THE PROFILES OF MULTIPATH CHANNELS

CHAN-NEL	TAGGING	1	2	3	4	5	6
Brazil A	Delay (us)	0.0	0.15	2.22	3.05	5.86	5.93
Brazil A	Loss (dB)	0.0	-13.8	-16.2	-14.9	-13.6	-16.4
Brazil B	Delay (us)	0.0	0.30	3.50	4.40	9.50	12.7
Brazil B	Loss (dB)	0.0	-12.0	-4.0	-7.0	-15.0	-22.0

TABLE VI
THE TESTING RESULTS BETWEEN MULTIMEDIA SERVICES

CHANNEL	ORIGINAL SERVICE		ADDITIONAL SERVICE	
	Mode	Threshold	Mode	Threshold
AWGN	64-QAM/0.6	15.0 dB	4-QAM/0.4	1.8 dB
Brazil A	64-QAM/0.6	16.8 dB	4-QAM/0.4	3.0 dB
Brazil B	64-QAM/0.6	18.0 dB	4-QAM/0.4	3.6 dB

V.CONCLUSIONS

In this paper, the concept of the PSC in time-frequency domain is introduced for DTMB systems, and the enhanced DTMB datacasting scheme with backward compatibility is discussed. Both theoretical analyses and testing results in the lab have proven that with lower power consumption and multiple QoS requirements in the new-service receivers while keeping the existing DTMB receivers unchanged, this novel DTMB datacasting approach can efficiently support multiple services over DTMB systems.

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